METHODS FOR THE MANUFACTURING OF MICROMACHINED STRUCTURES AND MICROMACHINED STRUCTURES MANUFACTURED USING SUCH METHODS

This invention relates to methods for the manufacturing of m icromachined structures and micromachined structures manufactured using such methods. The methods may i.a. be used in connection with the release of moving parts of micromachined structures.

Background

Micromachining allows the manufacturing of e g sensors and actuators with dimensions of nanometers to centimeters. Specific examples of micromachined objects include motors, pumps, accelerometers, pressure sensors, chemical sensors, valves, micro-motion systems and grippers. Overall surveys of micromachining are found e.g. in Ref. 1, 2 and 3. Three broad classes of micromachining are known: surface micromachining, bulk micromachining and LIGA and its variations.

In surface micromachining, layers are deposited and etched on one side of a wafer (Ref. 4). An example of an organic microactuator built using this technique is given in Ref. 5. Surface micromachining requires the selective etching of a temporary sacrificial layer to release a device that has been patterned from overlying structural layers. Many combinations of sacrificial/structural layers are possible, as long as the underlying sacrificial layer can be preferentially removed. Sacrificial layers consist of diverse materials, often SiO_2 or phosphosilicate glass, but also aluminum, photoresist, polyimide, porous silicon etc.

This is in contrast with bulk micromachining, in which structures are made directly from a silicon wafer, or wafers of another substrate material, such as gallium arsenide, GaAs, by selectively etching away unwanted

parts from the front and/or back sides of the wafer (Ref. 6). Bulk micromachining has been used for membranes, pumps and accelerometers. Two or more substrates can also be bonded together and etched. Surface and bulk micromachining methods are compared in Ref. 1 and Ref. 7.

LIGA, and its variations, involve patterning photoresist or some other suitable polymer using x-rays or ultraviolet light and depositing material into the resulting holes in the resist by electroplating. This method alone produces parts that are loose, and moving machines built from these parts must be assembled by hand. LIGA can also be combined with the sacrificial layer method (Ref. 8).

Prior Art

The only prior art method used for the release of moving parts of micromachined structures is the sacrificial layer method, which is briefly described above. This method consists of liberating mechanical structures by under-etching another underlaying thin layer to allow components free rotation, translation, or bending. Draw-backs of this method are mentioned i.a. in Ref. 9 and 10.

The sacrificial layer method is briefly described below with reference to the enclosed Figures 1a,b through 5a,b. A substrate, such as a silicon wafer with or without previously deposited layers and/or devices, is covered, e.g. through vacuum evaporation, with a so-called sacrificial layer. The sacrificial layer is patterned so that it only partly covers the substrate. Over the substrate and the sacrificial layer is deposited a further structural layer. The structural layer is patterned so that the remaining portion partly covers the exposed part of the substrate and partly

covers the sacrificial layer. Multiple levels of sacrificial layers and thereon deposited structural layers may be deposited and patterned. After the structural layers are applied, the sacrificial layers are removed by under-etching, thereby freeing overlying parts of the micromachined device.

Objects of the Invention

The above described method for making micromachined structures using sacrificial layer(s) have drawbacks such as the need for protecting specific layers from chemical and mechanical attack during removal of the sacrificial layer(s), timeconsuming under-etching for the release of the large-area structural layer(s) and difficulties in removing the sacrificial layer(s) from underneath overlying layer(s). (Ref z).

Accordingly, a first object of the present invention is to provide a novel method for the manufacture of micromachined structures without the drawbacks of prior art methods in accordance with Claim 1.

A second object of the invention is micromachined structures being manufactured with the above-mentioned method.

Other objects of the invention will become apparent to one skilled in the art, and still other objects will become apparent hereinafter.

Figures

Figures 1a,b through 13a,b are schematic and not to scale. Vertical dimensions are greatly exaggerated.

Fig 1a is a cross sectional view of a sacrificial layer deposited on a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 1b is a top view of a sacrificial layer deposited on a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 2a is a cross sectional view of a patterned sacrificial layer deposited on a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 2b is a top view of a patterned sacrificial layer deposited on a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 3a is a cross sectional view of a structural layer deposited over both a patterned sacrificial layer and a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 3b is a top view of a structural layer deposited over both a patterned sacrificial layer and a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 4a is a cross sectional view of a patterned structural layer deposited over both a patterned sacrificial layer and a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 4b is a top view of a patterned structural layer deposited over both a patterned sacrificial layer and a substrate for a micromachined structure manufactured with the sacrificial layer method.

Fig 5a is a cross sectional view of a released structural layer after the sacrificial layer has been removed for a micromachined structure manufactured with the sacrificial layer method.

Fig 5b is a top view of a released structural layer after the sacrificial layer has been removed for a

micromachined structure manufactured with the sacrificial layer method.

Fig 6a is a cross sectional view of the first step in the manufacturing of the structure according to Example 1, the deposition of the Cr layer.

Fig 6b is a top view of the first step in the manufacturing of the structure according to Example 1, the deposition of the Cr layer.

Fig 7a is a cross sectional view of the second step in the manufacturing of the structure according to Example 1, the patterning of the Cr layer.

Fig 7b is a top view of the second step in the manufacturing of the structure according to Example 1, the patterning of the Cr layer.

Fig 8a is a cross sectional view of the third step in the manufacturing of the structure according to Example 1, the deposition of the Au layer.

Fig 8b is a top view of the third step in the manufacturing of the structure according to Example 1, the deposition of the Au layer.

Fig 9a is a cross sectional view of the fourth step in the manufacturing of the structure according to Example 1, the deposition of the PPy layer.

Fig 9b is a top view of the fourth step in the manufacturing of the structure according to Example 1, the deposition of the PPY layer.

Fig 10a is a cross sectional view of the fifth step in the manufacturing of the structure according to Example 1, the patterning of the PPY layer.

Fig 10b is a top view of the fifth step in the manufacturing of the structure according to Example 1, the patterning of the PPY layer.

Fig 11a is a cross sectional view of the sixth step in the manufacturing of the structure according to Example 1, the patterning of the Au layer.

Fig 11b is a top view of the sixth step in the manufacturing of the structure according to Example 1, the patterning of the Au layer.

Fig 12a is a cross sectional view of the seventh step in the manufacturing of the structure according to Example 1, the removal of the remaining photoresist.

Fig 12b is a top view of the seventh step in the manufacturing of the structure according to Example 1, the removal of the remaining photoresist.

Fig 13a is a cross sectional view of the eighth step in the manufacturing of the structure according to Example 1, the electrochemical oxidation/reduction of PPy to induce the bilayer to bend and release from the surface.

Fig 13b is a top view of the eighth step in the manufacturing of the structure according to Example 1, the electrochemical oxidation/reduction of PPy to induce the bilayer to bend and release from the surface.

Fig 14a,b,c,d,e is a series of photographs taken with an overhead view through a microscope, of the completed devices bending/straightening due to electrochemical oxidation/reduction.

Fig 15a is a cross sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using as a first layer 3 a thin film on a simple, flat substrate 1.

Fig 15b is a cross sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using as a first layer 3 a bound chemical monolayer on a simple, flat substrate 1.

Fig 15c is a cross sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using as a first layer 3 a bound chemical monolayer on a simple,

flat substrate 1 with a previously attached and patterned second chemical monolayer on the surface 2.

Fig 16a is a cross sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using a substrate 1 with an outer surface having at least one relatively smooth area 12 and one area with increased roughness 14.

Fig 16b is a cross-sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using a substrate 1 that has deposited over it a first layer 22 with an outer surface having at least one relatively smooth area 23 and one area with increased roughness 24.

Fig 17 is a cross sectional view of one implementation of the present method for manufacturing at least partially releasable micromachines using as the first layer of the micromachine an adhesive thin film 33 on a simple, flat substrate 1.

Summary of the Invention

The present method for manufacturing micromachined structures is briefly described below in Examples 1 - 5 with reference to the Figures 6a,b through 17. A micromachine is a micromachined structure.

The method for the release of parts of a micromachine relies on a difference in adhesiveness of different parts of the surface under the micromachine to the micromachine or a difference in adhesiveness of different parts of the micromachine to the surface. This difference in adhesivity can be accomplished chemically, as in Examples 2 and 3 below, or mechanically, as in Examples 4 and 5 below, but other methods for accomplishing the difference in adhesivity are not excluded.

Detailed description of the invention

The following examples are intended to illustrate but not to limit the scope of the invention.

Example 1.

Bilayer actuators were manufactured in accordance with the below description with reference to the Figures 6a,b through 14a-e.

Standard 3-inch diameter silicon (Si) CZ wafers, purchased from Okmetic, Espoo, Finland, 380 micrometers thick, (100) orientation, p-type, boron-doped, 1-10 Ohm-cm conductivity, were used as substrates. Other substrates that could have been used include glass slides and SiO_2-covered wafers.

On the polished side of the wafers, a 30Å-thick adhesive layer of chromium (Cr) was deposited by vacuum evaporation (Fig 6a,b). The Cr layer was then patterned by wet chemical etching to leave a rectangular opening in the Cr inside which the Si was exposed (Fig 7a,b). The base of the bilayer actuators would later be fixed to the edge of the rectangle, and the rest of the actuator would lift off the bare Si areas. Other materials, such as titanium (Ti), to which the subsequent layer, see below, also adheres could have been used instead of Cr. The patterning was done by spin-coating the Cr layer with photo resist (Microposit 1818S Photo Resist, Shipley Europe Ltd., Coventry, England) at 8000 rpm for 30 seconds on a Headway Research Inc., Garland, Texas spinner followed by soft baking at 100°C for 90 seconds on a hot plate. The resist was exposed to UV light through a Cr/glass mask (mask blanks from Ulcoat, Tokyo, Japan) using a mask aligner (Karl Süss KG, type 401000, München, Germany) for 6 seconds at an intensity of approximately 5mW/cm^2

and at a wavelength of 365 nm. The resist was developed for 60 seconds in Microposit 351 Developer diluted 5:1 in water. The Cr was then etched in a standard Cr-etch solution of 3.5 g $Ce(SO_4)_2 \cdot 4H_2O$, 17.5 ml HNO_3 (65%), and 32.5 ml H_2O. All chemicals were purchased from E. Merck, Darmstadt, Germany. After the Cr was etched, the resist was stripped with remover Microposit Remover 1112A diluted with an equal amount of water. Developing, etching and stripping were done at room temperature.

Over the patterned Cr layer, a 200Å-thick layer of gold (Au) was deposited by vacuum evaporation (Fig 8a,b). Immediately prior to the evaporation, the Cr layer was etched briefly in Cr-etchant (described above), rinsed in a dilute nitric acid solution, rinsed in water, and blown dry with a stream of nitrogen to remove any native oxide. Because in subsequent steps, see below, a conducting polymer film was used, the choice of metal for this layer was restricted: it was essential for this particular device to have used Au or another noble metal film. Otherwise, the metal could have reacted to form surface species that would have prevented the growth and/or adhesion of the conducting polymer.

Polypyrrole (PPy), a conducting polymer, formed the second layer of the bilayer actuator. It was polymerized electrochemically to a thickness of 3000-5000Å over the gold surface at a constant 0.6V in a solution of 0.1M pyrrole monomers. purchased from E. Merck and distilled prior to use, and 0.1M of the sodium salt of dodecylbenzenesulfonate (Na·DBS), from Aldrich, Steinheim, Germany, in deionized water (Fig 9a,b).

Resist was spin coated over the PPy, soft-baked, exposed, and developed as described above. The PPy was then etched by dry chemical etching using reactive ion etching (RIE) in an oxygen plasma (Fig 10a,b), leaving

strips of various sizes, e g 30 µm x 1000 µm in area. Although PPy was used in this example, any other conducting polymer or voulme-changing polymers could have been used, icluding polyaniline, polythiophene, polypyrrole, derivatives of these polymers, and copolymers of any of these. This was demonstrated in macroscopic actuators - see Ref. 11 and Ref. 12. The polymer layer can be electrochemically synthesized, as in the above example, or can be chemically polymerized and spin-coated.

The exposed Au was etched away (Fig 11a,b) using a standard gold-etch solution of 1g·I_2, 2g Kl and 50 ml H_2O (chemicals purchased from E. Merck). The overlying resist/PPy layers protected the Au underneath from chemical attack. After this etching, Au was left only under the PPy. The photoresist remaining over the PPy was removed by RIE in an oxygen plasma. The plasma was turned off when the PPy was exposed (Fig 12a,b).

Electrochemical oxidation/reduction of the PPy layer in an electrolyte, such as 0.1 M Na·DBS (purchased from E. Merck) in deionized water, resulted in a change in its volume. The completed bimetal actuator, consisting of the gold and the PPy, therefore bent, and the bilayer released itself from the surface (Fig 13a,b). Photographs taken through a microscope showing a top view of these bilayers curling into spirals are shown in Fig 14a,b,c,d,e.

Although electrochemically driven changes in the volume of conducting polymers were used to drive the devices in this example, other possibilities exist for actuation and could have been used instead, including: piezoelectricity, solvent swelling, thermal expansion, chemical interactions, reaction to exposure to radiation, phase changes, or other stimuli.

Example 2

A micromachine may be manufactured in accordance with the below description with reference to Figures 15a,b,c. The following steps a) to g) are to be carried out:

a) a substrate 1 with an outer surface 2 is at least partly covered with a first layer 3 which is strongly adherent to the outer surface 2 and of which at least its outer surface 4, being the surface of the first layer 3 not adjacent to the outer substrate surface 2, has another adhesiveness than the outer substrate surface 2,

b) the first layer 3 is at least partly patterned,

c) a second layer 5 which is the bottom-most layer of the to-be-deposited layers comprising the micromachine, is deposited onto the substrate 2 and the first layer 3, the second layer 5 having an adhesiveness such that at least its inner surface 6 adheres differently to the outer surface 4 of the now patterned first layer 3 than those parts of the substrate surface 2 which are not covered by the patterned first layer 3,

d) if desired, the second layer 5 is patterned,

e) possibly remaining further layers 7 comprising the micromachine are deposited onto the second layer 5 and possibly also onto the first layer 3 and/or the substrate 1 and are patterned according to the design of the micromachine, and

f) if the second layer 5 adheres to the first layer 3 but not to the substrate 1, or only weakly to the

substrate 1, then the completed micromachine will be affixed to the substrate 1 at points where it is in contact with the outer surface 4 of the first layer 3, but will be free to come off the substrate 1 at points where it is in contact with the outer surface 2, or

g) if on the other hand the second layer 5 adheres to the substrate 1 but not to the first layer 3, or only weakly to the first layer 3, then the completed micromachine will be affixed to the substrate 1at points where it is in contact with the outer surface 2, but will be free to come off the substrate 1 at points where it is in contact with the outer surface 4 of the first layer 3.

The substrate 1 may be simple, consisting of a single material, or may be a complex, previously fabricated or prepared article. Examples of the former include wafers comprising silicon, silicon dioxide or silicon carbide, gallium arsenide wafers, glass slides, metal sheets and plastic sheets. Examples of the latter include oxidized silicon wafers, silicon wafers with a deposited layer of silicon carbide, silicon wafers containing a possibly patterned chemical monolayer, and silicon wafers containing circuitry, sensors, or other micromachined structures. Other, nonlisted, materials and material combinations are not excluded.

The surface 2 may be flat, curved, rough, stepped, discontinuous, or containing channels, wells, pits, or holes, or covered, partly or wholly, with a monolayer. Other shapes are not excluded. Examples of flat surfaces include silicon wafers and glass slides. Examples of rough surfaces include etched glass slides or mechanically polished metal pieces. Examples of surfaces

containing channels or holes include etched silicon wafers.

The layers 3, 5 and 7 may be a metal film, a grown or deposited oxide, a polymer, or a chemical monolayer. Other materials are not excluded. Examples of metal films include gold, aluminum, and platinum. Examples of oxides include SiO_2 and phosphosilicate glass. Examples of polymers include polyimide and benzocyclobutene. Examples of monolayers include hexamethyldisilazane, over Si or SiO_2, and alkanethiols, over gold.

The following variations of the basic manufacturing method are possible: the layers are patterned at a point in the processing sequence other than where described above; other layers are deposited and patterned at any point in the above described sequence of steps that do not alter the essential points of the manufacturing method, for example because they lie adjacent to the layers 3, 5 and/or 7; or further processing is done to the layers in addition to patterning. An example of a different sequence for the patterning is that the second layer 5 is patterned after the deposition of additional layers 7 rather than before, as listed above. Examples of other layers that may be deposited include metals for electrical connection to the micromachined structure, alignment marks, circuitry, sensors and other micromachined structures. Examples of additional processing include doping of deposited polysilicon layers, growing of oxides on the deposited layers, annealing. Unlisted additional layers and unmentioned further processing steps are not excluded.

Example 3

A micromachine may be manufactured in accordance with the below description with reference to Figure 16a. The following steps a) to g) are to be carried out:

a) a substrate 1 with an outer surface having at least one relatively smooth area 12 and one area with increased roughness 14,

b) the area(s) with increased roughness 14 is (are) at least partly patterned,

c) a layer 15 which is the bottom-most layer of the to-be-deposited layers comprising the micromachine, is deposited onto the substrate 1, the layer 15 having an adhesiveness such that at least its inner surface 16 adheres differently to the relatively smooth area(s) 12 than to the area(s) with increased roughness 14.

d) if desired, the layer 15 is patterned,

e) possibly remaining further layers 17 comprising the micromachine are deposited onto the layer 15 and possibly also onto the relatively smooth area(s) 12 and/or the area(s) with increased roughness 14 and are patterned according to the design of the micromachine, and

f) if the layer 15 adheres to the area(s) with increased roughness 14 but not to the relatively smooth area(s) 12, or only weakly to the relatively smooth area(s) 12, then the completed micromachine will be affixed to the substrate 1 at points where it is in contact with the area(s) with increased roughness 14, but will be free to come off the substrate 1 at points where it is in contact with the relatively smooth area(s) 12, or

g) if on the other hand the layer 15 adheres to relatively smooth area(s) 12 but not to the area(s) with increased roughness 14, or only weakly to the area(s) with increased roughness 14, then the completed micromachine will be affixed to the substrate 1 at points where it is in contact with the relatively smooth area(s) 12, but will be free to come off the substrate 1 at points where it is in contact with the area(s) with increased roughness 14.

The substrate 1 may be simple, consisting of a single material, or may be a complex, previously fabricated or prepared article. Examples of the former include wafers comprising silicon, silicon dioxide or silicon carbide, gallium arsenide wafers, glass slides, metal sheets and plastic sheets. Examples of the latter include oxidized silicon wafers, silicon wafers with a deposited layer of silicon carbide, silicon wafers containing a possibly patterned chemical monolayer, and silicon wafers containing circuitry, sensors, or other micromachined structures. Other, nonlisted, materials and material combinations are not excluded.

The areas 12 and 14 may be flat, curved, stepped, discontinuous, or containing channels, wells, pits, or holes. Other topographies are not excluded. Examples of flat areas include new silicon wafers and glass slides. Examples of areas containing channels or holes include etched silicon wafers.

The area(s) with increased roughness 14 may be produced by wet or dry chemical etching or by mechanical polishing, but other methods are not excluded.

The layers 15 and 17 may be metal films, grown or deposited oxides, or polymers. Other materials are not excluded. Examples of metal films include gold,

aluminum, and platinum. Examples of oxides include SiO_2 and phosphosilicate glass. Examples of polymers include polyimide and benzocyclobutene.

The following variations of the basic manufacturing method are possible: the layers are patterned at a point in the processing sequence other than where described above; other layers are deposited and patterned at any point in the above described sequence of steps that do not alter the essential points of the manufacturing method, for example because they lie adjacent to the layers 15 and/or 17; or further processing is done to the layers in addition to patterning. An example of a different sequence for the patterning is that the layer 15 is patterned after the deposition of additional layers 17 rather than before, as listed above.

Examples of other layers that may be deposited include metals for electrical connection to the micromachined structure, alignment marks, circuitry, sensors and other micromachined structures. Examples of additional processing include doping of deposited polysilicon layers, growing of oxides on the deposited layers, annealing. Unlisted additional layers and unmentioned further processing steps are not excluded.

Example 4

A micromachine may be manufactured in accordance with the below description with reference to Figure 16b. The below steps a) to g) are to be carried out:

a) a substrate 1 has deposited over it a first layer 22 with an outer surface having at least one relatively smooth area 23 and one area with increased roughness 24,

b) the area(s) with increased roughness 24 is (are) at least partly patterned,

c) a second layer 25 which is the bottom-most layer of the to-be-deposited layers comprising the micromachine, is deposited onto the substrate 1, the second layer 25 having an adhesiveness such that at least its inner surface 26 adheres differently to the relatively smooth area(s) 23 than to the area(s) with increased roughness 24,

d) if desired, the second layer 25 is patterned,

e) possibly remaining further layers 27 comprising the micromachine are deposited onto the layer 25 and possibly also onto the relatively smooth area(s) 23 and/or the area(s) with increased roughness 24 and are patterned according to the design of the micromachine, and

f) if the second layer 25 adheres to the area(s) with increased roughness 24 but not to the relatively smooth area(s) 23, or only weakly to the relatively smooth area(s) 23, then the completed micromachine will be affixed to the substrate 1 at points where it is in contact with the area(s) with increased roughness 24, but will be free to come off the substrate 1 at points where it is in contact with the relatively smooth area(s) 23, or

g) if on the other hand the layer 25 adheres to relatively smooth area(s) 23 but not to the area(s) with increased roughness 24, or only weakly to the area(s) with increased roughness 24, then the completed micromachine will be affixed to the

substrate 1 at points where it is in contact with the relatively smooth area(s) 23, but will be free to come off the substrate 1 at points where it is in contact with the area(s) with increased roughness 24.

The substrate 1 may be simple, consisting of a single material, or may be a complex, previously fabricated or prepared article. Examples of the former include wafers comprising silicon, silicon dioxide or silicon carbide, gallium arsenide wafers, glass slides, metal sheets and plastic sheets. Examples of the latter include oxidized silicon wafers, silicon wafers with a deposited layer of silicon carbide, silicon wafers containing a possibly patterned chemical monolayer, and silicon wafers containing circuitry, sensors, or other micromachined structures. Other, nonlisted, materials and material combinations are not excluded.

The areas 23 and 24 of the first layer 22 may be flat, curved, stepped, discontinuous, or containing channels, wells, pits, or holes. Other topographies are not excluded. Examples of flat areas include silicon wafers and glass slides. Examples of areas containing channels or holes include etched silicon wafers.

The area(s) with increased roughness 24 may be produced by wet or dry chemical etching or by mechanical polishing, but other methods are not excluded.

The layers 25 and 27 may be metal films, grown or deposited oxides, or polymers. Other materials are not excluded. Examples of metal films include gold, aluminum, and platinum. Examples of oxides include SiO_2 and phosphosilicate glass. Examples of polymers include polyimide and benzocyclobutene.

The following variations of the basic manufacturing method are possible: the layers are patterned at a point

in the processing sequence other than where described above; other layers are deposited and patterned at any point in the above described sequence of steps that do not alter the essential points of the manufacturing method, for example because they lie adjacent to the layers 22, 25 and/or 27; or further processing is done to the layers in addition to patterning. An example of a different sequence for the patterning is that the second layer 25 is patterned after the depo-sition of additional layers 27 rather than before, as listed above.

Examples of other layers that may be deposited include metals for electrical connection to the micromachined structure, alignment marks, circuitry, sensors and other micromachined structures. Examples of additional processing include doping of deposited polysilicon layers, growing of oxides on the deposited layers, annealing. Unlisted additional layers and unmentioned further processing steps are not excluded.

Example 5

A micromachine may be manufactured in accordance with the below description with reference to Figure 17. The below steps a) to f) are to be carried out:

a) a substrate 1 with an outer surface 32 is at least partly covered with a first layer 33 which has an inner surface 34 strongly adhering to the outer surface 32 and which is the bottom-most-layer of the to-be-deposited layers comprising the micromachine,

b) the first layer 33 is at least partly patterned,

c) a second layer 35 which has an inner surface 36 is deposited onto the substrate 1 and possibly also onto the first layer 33, the second layer 35 having an adhesiveness such that its inner surface 36 adheres less strongly to the outer surface 32 than does the inner surface 34, but that its inner surface 36 adheres strongly to the first layer 33,

d) if desired, the second layer 35 is patterned,

e) possibly remaining further layers 37 comprising the micromachine are deposited onto the second layer 35 and possibly also onto the first layer 33 and/or the outer surface 32 and are patterned according to the design of the micromachine, and

f) since the first layer 33 adheres to the outer surface 32, but the second layer 35 does not adhere or adheres only weakly with the surface 32, then the completed micromachine will be affixed to the substrate 1 at points where it is in contact with the outer surface 32 but will be free to come off the substrate 1 at points where the second layer 35 is in contact with the outer surface 32.

The substrate 1 may be simple, consisting of a single material, or may be a complex, previously fabricated or prepared article. Examples of the former include wafers comprising silicon, silicon dioxide or silicon carbide, gallium arsenide wafers, glass slides, metal sheets and plastic sheets. Examples of the latter include oxidized silicon wafers, silicon wafers with a deposited layer of silicon carbide, silicon wafers containing a possibly patterned chemical monolayer, and silicon wafers containing circuitry, sensors, or other

micromachined structures. Other, nonlisted, materials and material combinations are not excluded.

The surface 32 may be flat, curved, rough, stepped, discontinuous, or containing channels, wells, pits, or holes. Other shapes are not excluded. Examples of flat surface include silicon wafers and glass slides. Examples of rough surfaces include etched glass slides or mechanically polished metal pieces. Examples of surfaces containing channels or holes include etched silicon wafers.

The layers 33, 35 and 37 may be metal films, grown or deposited oxides, or polymers. Other materials are not excluded. Examples of metal films include gold, aluminum, and platinum. Examples of oxides include SiO_2 and phosphosilicate glass. Examples of polymers include polyimide and benzocyclobutene.

The following variations of the basic manufacturing method are possible: the layers are patterned at a point in the processing sequence other than where described above; other layers are deposited and patterned at any point in the above described sequence of steps that do not alter the essential points of the manufacturing method, for example because they lie adjacent to the layers 33, 35 and/or 37; or further processing is done to the layers in addition to patterning. An example of a different sequence for the patterning is that the second layer 35 is patterned after the deposition of additional layers 37 rather than before, as listed above.

Examples of other layers that may be deposited include metals for electrical connection to the micromachined structure, alignment marks, circuitry, sensors and other micromachined structures. Examples of additional processing include doping of deposited polysilicon layers, growing of oxides on the deposited

layers, annealing. Unlisted additional layers and unmentioned further processing steps are not excluded.

The difference between this Example 5 and Example 2 is that whereas in Example 2, the surface is modified to produce areas with different adhesivity to the micromachine, or parts of the micromachine, in this Example 5, the micromachine is made up of parts with different adhesitivity to the substrate surface. For instance, if the micromachine were made up of chromium and gold parts, and the substrate was silicon; then parts of the micromachine made of chromium would stick to the surface, but the gold parts would not.

Example 6

A micromachine may be manufactured in accordance with the below description with reference to Figure 15a. The following steps a) to g) are to be carried out:

a) a substrate 1 with an outer surface 2 is at least partly covered with a first layer 3 which is strongly adherent to the substrate 1 and of which at least its outer surface 4, being the surface of the first layer 3 not adjacent to the outer substrate surface 2, has another adhesiveness than the outer substrate surface 2,

b) said first layer 3 is at least partly patterned,

c) a second layer 5, which is the bottom-most layer of the to-be-deposited layers comprising the micromachine, is deposited onto the said substrate 1 and first layer 3, said second layer 5 having an adhesiveness such that at least its inner surface 6 adheres differently to the outer surface 4 of the patterned first layer 3 than to those parts of the

outer substrate surface 2 of the substrate 1 which are not covered by the patterned first layer 3,

d) the possibly remaining further layers 7 comprising the micromachine are deposited onto the second layer 5 and are patterned according the design of the micromachine,

e) the second layer 5 is patterned, and

f) if the second layer 5 adheres to the first layer 3 but not to the substrate 1, or only weakly to the substrate 1, and the micromachines were manufactured to lie exclusively over those areas of the outer substrate surface 2 which were not covered by the patterned first layer 3, then the completed micromachines will be free to come off the substrate, resulting in completely loose structures, or

g) if on the other hand the second layer 5 adheres to the substrate 1 but not to the first layer 3, or only weakly with the first layer 3, and the micromachines were manufactured to lie exclusively over those areas covered by the patterned first layer 3, then the completed micromachines will be free to come off the substrate, resulting in loose structures.

The substrate 1 may be simple, consisting of a single material, or may be a complex, previously fabricated or prepared article. Examples of the former include silicon wafers, galium arsenide wafers, glass slides, metal sheets, and plastic sheets. Examples of the latter include oxidized silicon wafers, silicon

wafers with a deposited layer of silicon carbide, silicon wafers contianing a possibly patterned chemical monolayer, and silicon wafers containing circuitry, sensors, or other micromachines. Other, nonlisted, materials and material combinations are not excluded.

The surface 2 may be flat, curved, rough, stepped, discontinuous, or containing channels, wells, pits, or holes. Other shapes are not excluded. Examples of flat surfaces include silicon wafers and glass slides. Examples of rough surfaces include etched glass slides or mechanically polished metal pieces. Examples of surfaces containing channels or holes include etched silicon wafers

The layers 3, 5 and 7 may be a metal film, a grown or deposited oxide, a polymer, or a chemical monolayer. Other materials are not excluded. Examples of metal films include gold, aluminum, and platinum. Examples of oxides include SiO_2 and phosphosilicate glass. Examples of polymers include polyimide and benzocyclobutene. Examples of monolayers include hexamethyldisilazane over Si or SiO_2 and alkanethiols over gold.

The following variations of the basic fabrication method are not excluded: the layers are patterned at a point in the processing sequence other than where described above; other layers are deposited and patterned at any point in the above described sequence of steps that do not alter the essential points of the fabrication method, for example because they lie adjacent to the layers 3, 5 and 7; or further processing is done to the layers in addition to patterning. Examples of other layers that may be deposited include metals for electrical connection to the micromachine, alignment marks, circuitry, sensors, and other micromachines. Examples of additional processing include doping of deposited polysilicon layers, growing of

oxides on the deposited layers, and annealing. Unlisted additional layers and unmentioned further processing steps are not excluded.

Further characteristics

In all the above Examples as well as in other embodiments included in the present invention, the deposition of layers may be accomplished in different ways, such as spin-coating, vacuum deposition, sputtering and electrochemical processes. It is preferable that a layer is cleaned from unwanted contamination, oxides or other unwanted deposits prior to the deposition of subsequent layers.

In all the above Examples as well as in other embodiments included in the present invention, the patterning of layers may be accomplished in different ways according to the material of the respective layer and the dimensions to be realized. Photolitography and etching are the preferred methods, but the use of methods such as screen printing, lift-off and deposition through shadow masks are also possible.

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CLAIMS

1. Method for manufacturing a micromachined structure, c h a r a c t e r i z e d in that either the micromachined structure is manufactured over the surface of a substrate which is divided into surface areas with different adhesiveness to the micromachined structure or to parts of the micromachined structure, or that the micromachined structure is divided into parts which have surfaces areas with different adhesiveness to the substrate over which it is manufactured.

2. Method for manufacturing a micromachined structure according to Claim 1, c h a r a c t e r i z e d in that at the end of the manufacturing the micromachined structure is partly or wholly detached from the surface substrate and has at least one free-standing or moving part.

3. Method for manufacturing a micromachined structure according to Claim 1 or 2, c h a r a c t e r i z e d in that the difference in adhesiveness between different areas of the substrate surface and the micromachined structure or parts of the micromachined structure is achieved by providing a patterned adhesion-promoting layer on the substrate surface or a patterned adhesion-preventing layer on the substrate surface or patterned regions of roughness and smoothness on the substrate surface and/or patterned regions on the substrate surface that enable alloy formation with parts of the micromachined structure or patterned regions that allow molecular interprenetation with parts of the micromachined structure.

4. Method for manufacturing a micromachined structure according to Claim 1, 2 and 3, c h a r a c t e r i z e d in that the difference in adhesiveness between different areas of the substrate surface and the micromachined structure or parts of the micromachined structure is achieved by providing as parts of the micromachined structure adhesive and non-adhesive layers and/or layers with different degrees of roughness on those micromachined structure surfaces which are in contact with the substrate surface and/or one or more layers that enable alloy formation with the substrate and one or more other layers that do not enable alloy formation with the substrate and/or layers having different abilities to interpenetrate the substrate.

5. Method for manufacturing a micromachined structure according to any one of Claim 1, 2 and 3, c h a r a c t e r i z e d in that the difference in adhesiveness between different areas of the substrate surface and the micromachined structure or parts of the micromachined structure is achieved by providing different chemical compositions over different areas of the substrate surface and/or etching parts of the substrate surface to increase roughness and/or chemically polishing part of the substrate surface to increase smoothness.

6. Method for manufacturing a micromachined structure according to any one of Claim 1, 2 and 4, c h a r a c t e r i z e d in that the difference in adhesiveness between different areas of the substrate surface and the micromachined structure or parts of the micromachined structure is achieved by providing different chemical compositions on different parts of the micromachined structure.

7. Method for manufacturing a micromachined structure according to any one of Claim 1, 2, 3 and 5, c h a r a c t e r i z e d in that the substrate comprises an oxide or native oxide forming metal, that the adhesion-promoting layer essentially comprises an non-oxide-forming metal or a noble metal and that a bottom-most layer of the micromachined structure essentially comprises a noble metal.

8. Method for manufacturing a micromachined structure according to any one of the preceding claims, c h a r a c t e r i z e d in that the substrate comprises silicon, silicon dioxide, silicon carbide or glass; or silicon, silicon dioxide, silicon carbide or glass with overlying grown or deposited layers; or silicon, silicon dioxide, silicon carbide or glass with overlaying structures, devices or circuitry; or silicon, silicon dioxide, silicon carbide or glass which has already been partly micromachined structured.

9. Method for manufacturing a micromachined structure according to any one of Claim 3, 5 and 7, c h a r a c t e r i z e d in that the adhesion-promoting layer comprises chromium, titanium, nickel, or a mixtue comprising titanium, tungsten and nitrogen, or an alloy comprising titanium, tungsten and nitrogen.

10. Method for manufacturing a micromachined structure according to any one of the preceding claims, c h a r a c t e r i z e d in that a bottom-most layer of the micromachined structure comprises gold, platinum or palladium.

11. Method for manufacturing a micromachined structure according to any one of Claims 3 - 10, c h a r a c t e r i z e d in that layers to be defined are defined through a photolithographic process.

12. Method for manufacturing a micromachined structure according to any one of Claim 3 - 10, c h a r a c t e r i z e d in that layers to be patterned are patterned essentially through etching.

13. Method for manufacturing a micromachined structure according to Claim 12, c h a r a c t e r i z e d in that the etching is wet chemical etching.

14. Method for manufacturing a micromachined structure according to Claim 12, c h a r a c t e r i z e d in that the etching is dry chemical etching.

15. Method for manufacturing a micromachined structure according to Claim 12, c h a r a c t e r i z e d in that the etching is reactive ion etching.

16. Method for manufacturing a micromachined structure according to any one of the preceding claims, c h a r a c t e r i z e d in that a layer above a bottom-layer of the micromachined structure comprises a conducting polymer.

17. Method for manufacturing a micromachined structure according to Claim 16, c h a r a c t e r i z e d in that the conducting polymer comprises polypyrrole, polyanaline, or polythiophene, or their derivatives, or copolymers of any of these.

18. A micromachined structure, c h a r a c t e r i z e d in that the micromachined structure is manufactured over the surface of a substrate which is divided into surface areas with different adhesiveness to the micromachined structure or to parts of the micromachined structure.

19. A micromachined structure, c h a r a c t e r i z e d in that it is manufactured with a method according to any one of Claim 1 - 17.

ABSTRACT

Methods for the manufacturing of micromachined structures and micromachined structures manufactured using such methods.

Method for manufacturing a micromachined structure wherein the micromachined structure is manufactured over the surface of a substrate which is divided into surface areas with different adhesiveness to the micromachined structure or to parts of the micromachined structure.

At the end of the manufacturing the micromachined structure may be partly or wholly detached from the surface substrate thereby having at least one free-standing or moving part.

The invention also encompasses micromachined structures manufactured using the claimed methods.

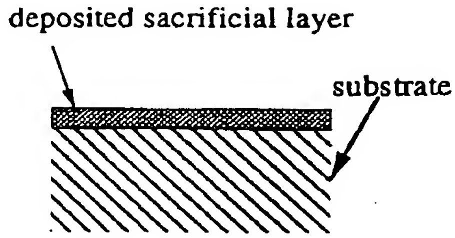

Fig 1a

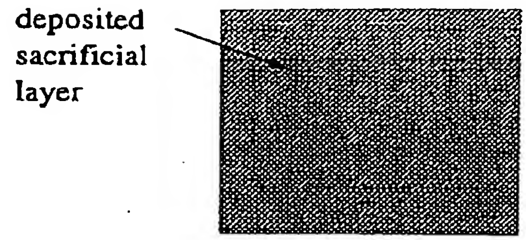

Fig 1b

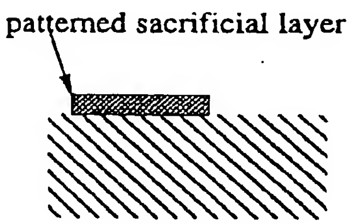

Fig 2a

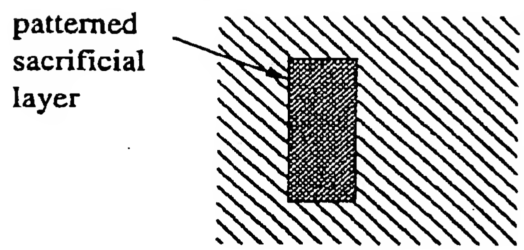

Fig 2b

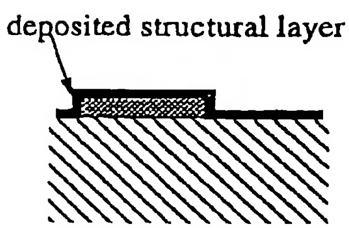

Fig 3a

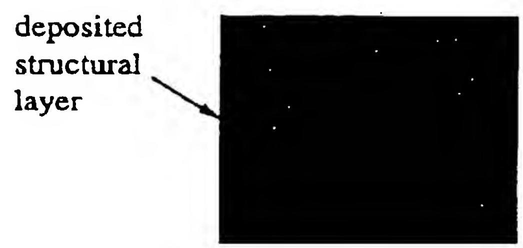

Fig 3b

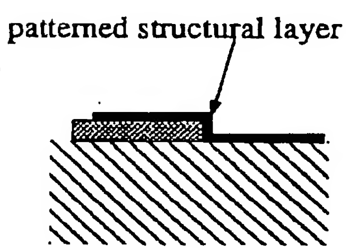

Fig 4a

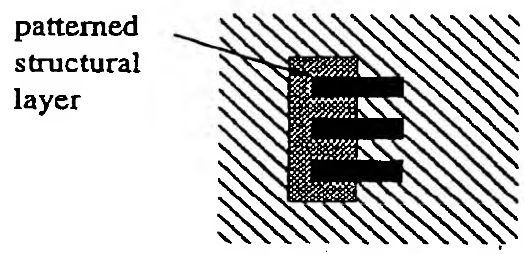

Fig 4b

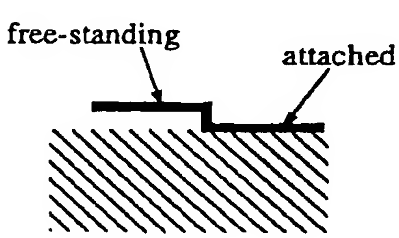

Fig 5a

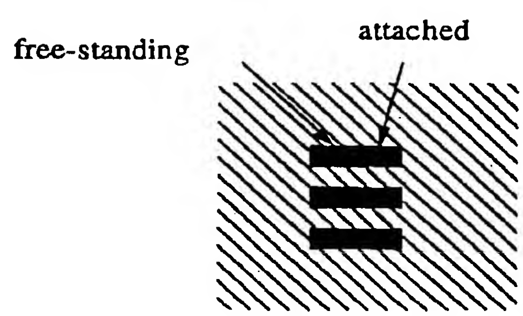

Fig 5b

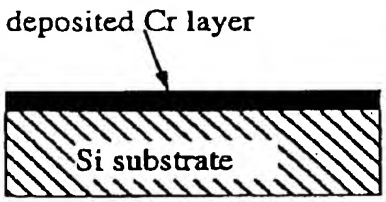

Fig 6a

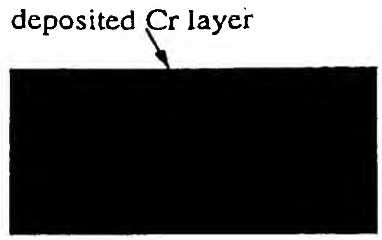

Fig 6b

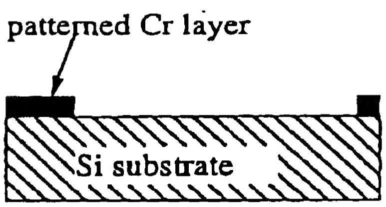

Fig 7a

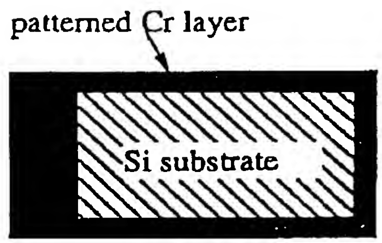

Fig 7b

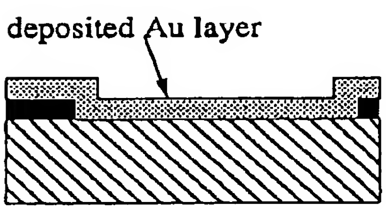

Fig 8a

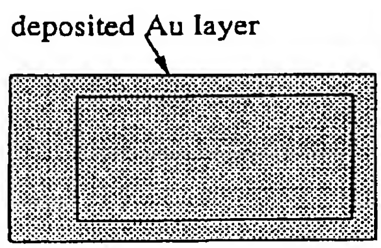

Fig 8b

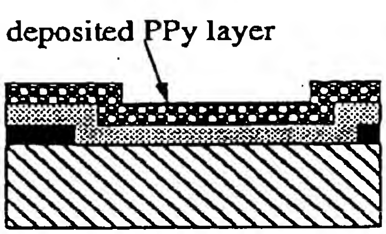

Fig 9a

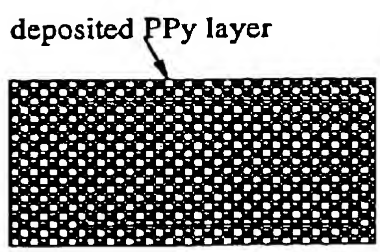

Fig 9b

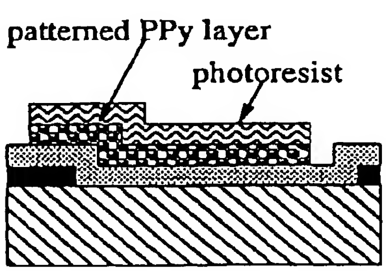

Fig 10a

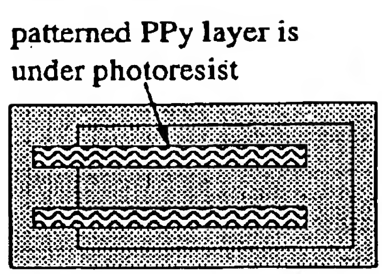

Fig 10b

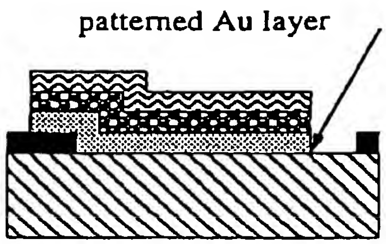

Fig 11a

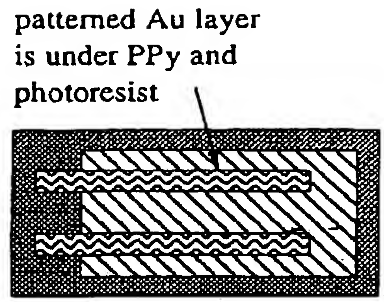

Fig 11b

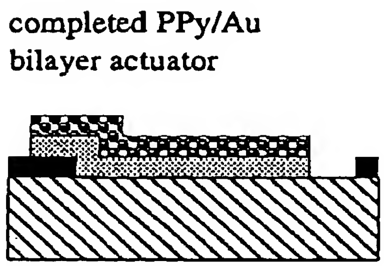

Fig 12a

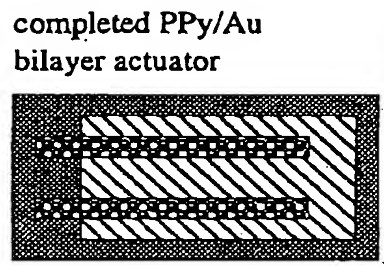

Fig 12b

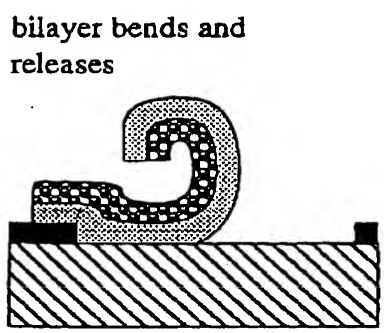

Fig 13a

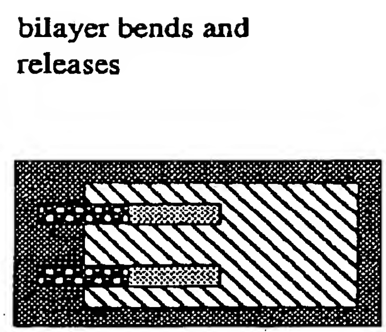

Fig 13b

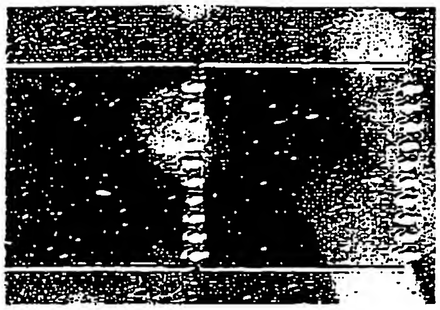

Fig 14e

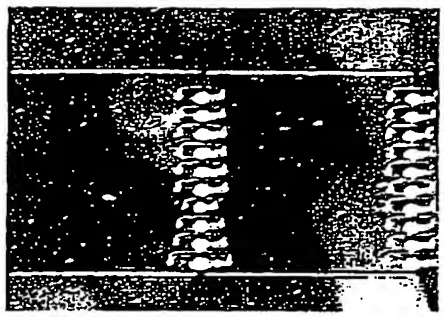

Fig 14d

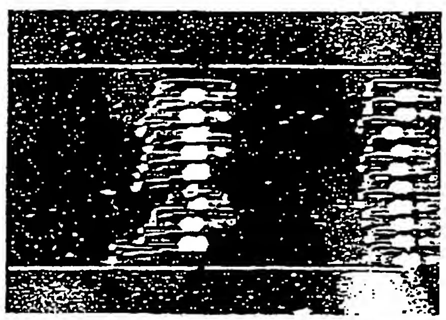

Fig 14c

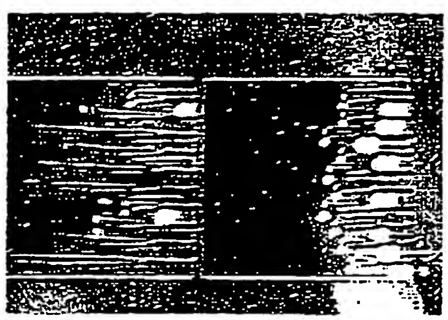

Fig 14b

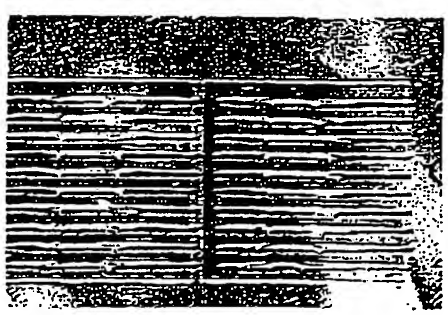

Fig 14a

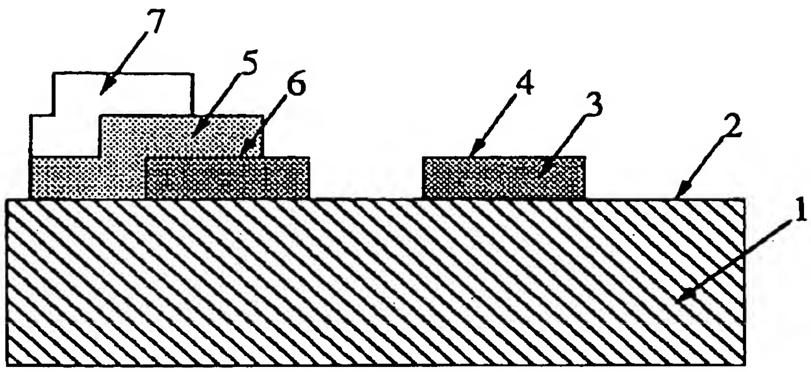

Figure 15a

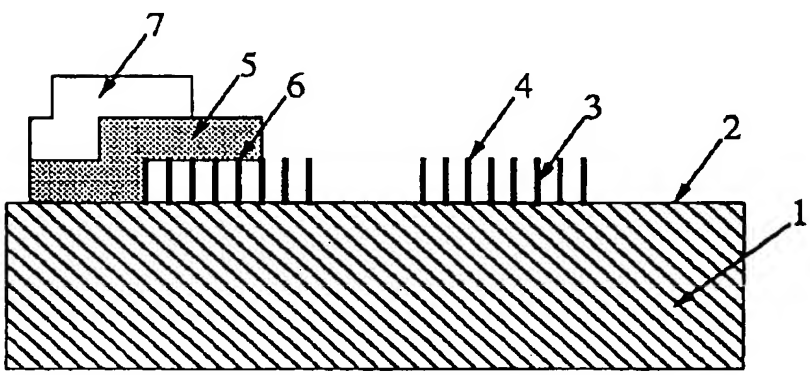

Figure 15b

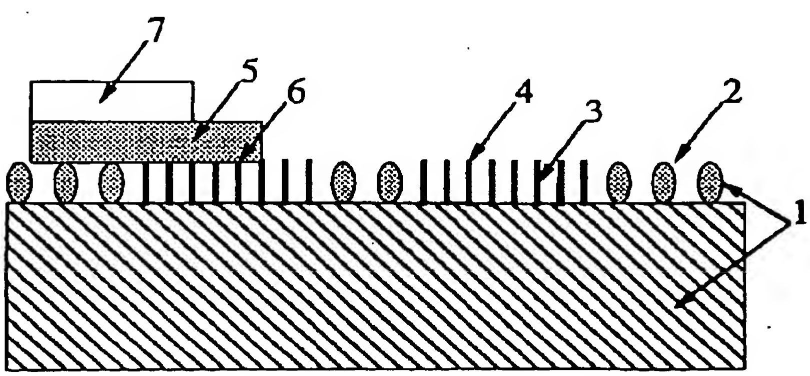

Figure 15c

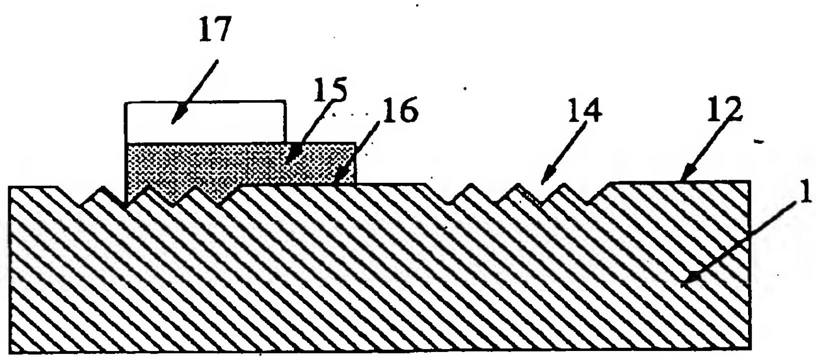

Figure 16a

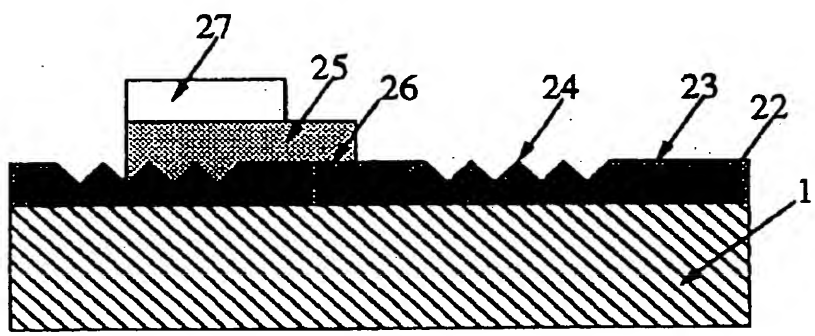

Figure 16b

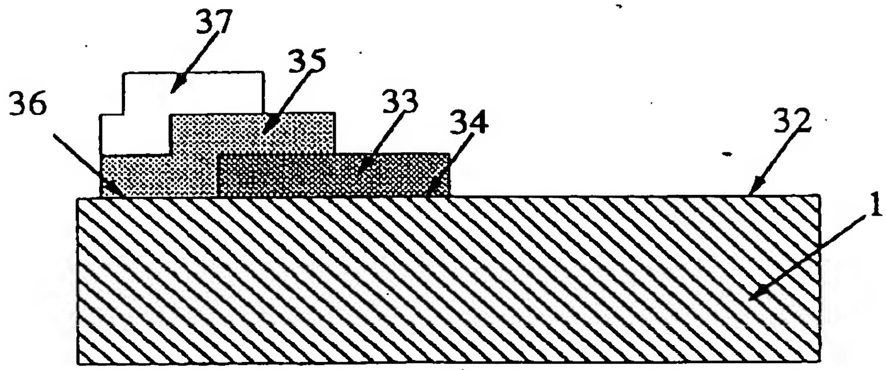

Figure 17